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Experience feedback and innovative pedagogical applications with HOME I/O

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Abstract: In the previous IFAC World Congress at Toulouse in 2017, HOME I/O was introduced as an innovative pedagogical tool. This software is the result of a R&D project between CReSTIC lab from the University of Reims Champagne-Ardenne (URCA) and Real Games, partially founded by the French Ministry of National Education, in order to design a virtual house adapted to control and STEM (Science, Technology, Engineering and Mathematics) education. The main idea, from the beginning, has been to bring a virtual house into the classroom, adapted to learners and teachers and usable from middle schools to universities. To perform this goal, a free soft PLC called CONNECT I/O, enables to connect HOME I/O to external automation technologies (e.g. PLC, Modbus TCP, OPC DA, microcontrollers...). All over the world, around 800 middle, high schools and universities use HOME I/O. Teachers and students' feed-back have been taken into account by updating HOME I/O with new add-ons and features like: a simpler licensing system (2016), Scratch 2.0 (2017) integration and Python 3.x integration (2019). This paper presents these new features and a selection of some innovative pedagogical applications performed by teachers from middle school, high school, university, and even primary school! HOME I/O seems to prove that it is possible to have one simulation tool adapted to different levels of training and enabling original pedagogical approaches: flipped classroom, pedagogic digital twin, learning from errors, projects...

Keywords: simulation tool, control education, innovative pedagogical approaches, STEM education, virtual house, digital twin

1. INTRODUCTION

HOME I/O software (Riera et al., 2017) is the result of a R&D project between CReSTIC lab from the University of Reims Champagne-Ardenne (URCA) and Real Games, partially founded by the French Ministry of National Education in order to design a virtual house adapted to control and STEM (Science, Technology, Engineering and Mathematics) education. The main idea, from the beginning, has been to bring a virtual house into the classroom, adapted to learners and teachers, usable from middle schools to universities. To perform this goal, a free soft PLC called CONNECT I/O, enables to connect HOME I/O to external automation technologies (e.g. PLC, Modbus TCP, OPC DA, microcontrollers...). All over the world (but principally in France), around 800 middle, high schools and universities use HOME I/O. Teachers and students' feed-back have been taken into account by updating HOME I/O with new add-ons and features like: a simpler licensing system (2016), Scratch 2.0 integration (2017) and Python 3.x integration (2019). This paper presents these new features and several innovative pedagogical applications, performed by teachers from middle school, high school, University, and even primary school. The first and the second section of the paper deals with a short presentation of HOME I/O and CONNECT I/O. The third part of the paper shows the updates and add-ons for

HOME I/O since the first release. The last part of the paper presents several innovative pedagogical applications where for instance virtual and real worlds are mixed and support new instructional strategy like flipped classroom.

2. HOME I/O: A VIRTUAL HOUSE FOR CONTROL AND STEM EDUCATION

HOME I/O (<https://realgames.co/home-io/>) is the result of «DOMUS» (2011-2014) a 3-year research and development project between the CReSTIC lab from the University of Reims Champagne-Ardenne and Real Games, a Portuguese company, which was partially founded by the French Ministry of National Education. HOME I/O is real time FPS (First Person Shooter) simulation software (figure 1) of a smart house and its surrounding environment. This software was built from the beginning to cover a large spread of educational applications in technology and engineering sciences (Riera et al., 2017). More than a simulator, HOME I/O has been designed to be a learning, experimenting and project development environment dedicated to students from middle schools, high schools and universities. All controllable objects can be used in three modes: wired, console or external (figure 2).

In wired mode, the house is not automated. This is a conventional electrical installation where all devices are

wired. It is the mode by default when you start HOME I/O. This mode enables to discover an “unsmart” virtual house. In the console mode (figure 3), the controllable objects are programmable through home automation box software by defining scenarios (lighting, motor, heating, intrusion security and domestic security). This mode has been initially designed for middle school because the functional aspect of smart home can be easily explained and understood by kids, without going into too technical considerations.



Fig. 1. HOME I/O



Fig. 2. Wired, console and external modes

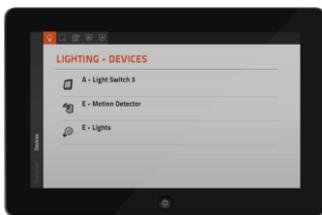


Fig. 3. HOME I/O console

In the external mode, inputs and outputs of each object can be used through HOME I/O SDK which is made of a .NET 2.0 assembly (EngineIO.dll). HOME I/O SDK opens the field of applications of HOME I/O. This makes it possible (and simple) for instance to control a room temperature with LabView (Riera et Vigario, 2017) or MATLAB. Hence, it becomes easy for instance for students to understand how a PID controller works. The external mode has been designed initially for high school and higher education. These 3 modes enable to modify the level of automation and offer a wide range of applications adapted to middle school, high school and university. In addition, HOME I/O is supplied with a free soft PLC called CONNECT I/O which uses HOME I/O SDK.

3. CONNECT I/O

CONNECT I/O enables HOME I/O to be easily integrated with automation technologies. With CONNECT I/O (figure 4), several functionalities can be implemented by drawing a diagram with nodes and linking them together. Basically, CONNECT I/O can be used for three different purposes:

- Control HOME I/O by designing a soft controller with function blocks.

- Connect HOME I/O to external automation technologies (e.g. PLC, Modbus, microcontrollers...). In this case, CONNECT I/O can be seen as a gateway between external technologies and the simulation.

- Perform acquisition and analysis of data coming from HOME I/O.

All these functionalities can be used at the same time and even extended by developing plugins.

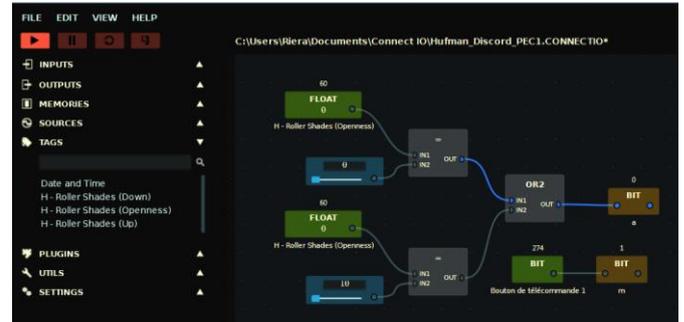


Fig. 4. CONNECT I/O: soft PLC for HOME I/O

CONNECT I/O has five different types of nodes, Inputs, Outputs, Memories, Sources and Nodes:

- Inputs: values read from HOME I/O (e.g. light switch is on or off).

- Outputs: values written to HOME I/O (e.g. turn a light on or off).

- Memories: generic values exchanged with the simulation (read/write). For example, if the simulation is running, the current simulation date and time, etc.

- Sources: nodes for generating values (e.g. a boolean, integer, float, string, etc.).

- Functional Nodes: nodes providing functionalities.

Indeed, Functional Nodes provide a wide range of functionalities, such as connectivity with PLC, interface boards, support for protocols and even arithmetic operations. Below is a list of major Functional Nodes and its functionalities.

- Function Blocks supplied nodes allowing CONNECT I/O to be used as a soft PLC and are compliant with the standard IEC 61131-3.

- Advantech USB 4750 and USB 4704 nodes provide respectively connectivity with an Advantech USB 4750 interface board or an Advantech USB 4704 interface board. It can be used for wiring PLC or any hardware type with digital or analog I/O.

- Data Analysis with Live Graph node plots data in real-time with LiveGraph (<http://live-graph.sourceforge.net/>).

- OPC DA Client node implements an OPC Client Data Access.

- Modbus TCP/IP Client and Modbus TCP/IP server nodes implement respectively a Modbus TCP/IP client and a Modbus TCP/IP server.

- PICAXE nodes provides connectivity with a PICAXE-20X2, 28X2 or 40X2 microcontroller simulated on the PICAXE Editor.

- SIEMENS nodes provide connectivity with Siemens PLC LOGO! 0BA7, LOGO! 0BA8, S7-300, S7-400 S7-1200 and S7-1500 through Ethernet. S7-PLCSIM (V5.4/5.5) node provides connectivity with Siemens S7-PLCSIM (V5.4/5.5).

Several plugins have been developed and given to the community through the web site <https://teachathomeio.com/>.

4. HOME I/O FEEDBACK AND UPDATES

Several changes in the pedagogical programs in middle and high schools have appeared in France since 2016. New instructional strategy and the learning of programming becomes very important. Consequently, it has been necessary to update HOME I/O with a new licensing system and 2 new features linked to programming languages: Scratch 2.0 for middle school and Python 3.x for high schools.

4.1 Simple licensing system

Today, education promotes new instructional strategy like flipped classroom. The flipped classroom intentionally shifts instruction to a learner-centered model in which time in the classroom is used to explore topics in greater depth and create meaningful learning opportunities while students are initially introduced to new topics outside of the classroom. In a flipped classroom, “content delivery” may take a variety of forms. Often, video lessons prepared by the teacher or third parties are used to deliver content, although online collaborative discussions, digital research, and text readings may be used. Consequently, it is important to give to learners, digital tools to test and practice to perform home work. It is why, a 30 days demo mode of HOME I/O and a simple licensing system (just a file, which can be given to the learner, indicating on HOME I/O the school which owns the license) was carried in 2016.

4.2 HOME I/O and Scratch 2.0

As part of the reform of the middle school and new programs in Mathematics and Technology, Scratch is today the software that is recommended by the General Inspectorate of the French Ministry of Education. Consequently, in 2017 (Riera et al., 2019), a native connection to Scratch 2.0, using a web server, has been implemented in HOME I/O. This update has extended the pedagogical possibilities of HOME I/O, particularly for middle schools students, but not only (cf. paragraph 5.3). HOME I/O can be used together with Scratch 2.0 through scratch extensions. Data exchange between Scratch 2.0 and HOME I/O is done through a built-in web server in HOME I/O which is listening on port 9797. User may disable the web server or define a different listening port. A Scratch 2.0 template file includes the necessary HOME I/O extension blocks. After opening this file in Scratch, more blocks are available. In order to use HOME I/O devices in Scratch 2.0, they must be set to external mode first. A successful connection between Scratch and HOME I/O is indicated by a green light (figure 5).



Fig. 5. HOME I/O blocks in Scratch 2.0

4.3 HOME I/O and Python 3.x

The choice of Python 3.x to learn programming in French high schools was decided by the General Inspectorate of the French Ministry of Education in 2017. Python allows students to confront the accuracy and rigidity a syntax close to that of mathematical expressions. HOME I/O can be used together with Python 3.x. The Python Integration allows to write Python programs to interact with Home I/O devices. This means that it is possible to read and write to devices I/O points from Python programs. In order to access I/O points from Python, the devices must be set to External Mode first. HOME I/O / Python integration was developed on top of HOME I/O SDK and pythonnet. Python for .NET (pythonnet) is a package that gives Python programmer nearly seamless integration with the .NET 4.0+ Common Language Runtime (CLR) on Windows and Mono runtime on Linux and OSX. Python for .NET provides a powerful application scripting tool for .NET developers. Using this package one can script .NET applications or build entire applications in Python, using .NET services and components Python for .NET is currently compatible and tested with Python releases 2.7 and 3.5-3.7. Current releases are available at the Python for .NET website: <http://pythonnet.github.io/>. HOME I/O is a 32 bit application, therefore a 32 bit release of Python, even HOME I/O runs on a 64 bit operating system, has to be used. It's important to note that the files built for the specific major release of the Python installed in the PC have to be used. For example, if Python 3.7.x is used, files built specifically for this major release (3.7) have to be used.

In figure 6, a Python code sample to flash 5 times the light in the living room is proposed. With pythonnet, one can use HOME I/O SDK made of a .NET 2.0 assembly (EngineIO.dll) with Python, as it is possible in C# for instance. This assembly enables custom code to access the simulation I/O points. This feature has been highly requested by French high schools.



Fig. 6. HOME I/O with Python 3.x

Python integration with HOME I/O is new. Reims rectorship in France has decided in 2019 to promote this feature by supplying HOME I/O to referent high school teachers who are going to propose pedagogical activities for the new course “Digital Systems and Technology”

In the following of the paper, several innovative pedagogical contributions performed by teachers are presented. The

objective is only to show original applications which were not really thought when HOME I/O was designed.

5. HOME I/O INNOVATIVE PEDAGOGICAL CONTRIBUTIONS

HOME I/O brings a virtual house suitable for control and STEM interdisciplinary education. In the following of the paper, several innovative pedagogical experiences which show the possibilities of HOME I/O. Some of the presented contributions can be found on the web site <https://teachathomeio.com/>.

5.1. HOME I/O at middle school

In France, several middle school teachers use HOME I/O in a multi-disciplinary approach. For instance, students have to perform a HOME I/O 3D SketchUp model (figure 7) from the blueprints.

Some teachers also use HOME I/O mixing virtual and real worlds. The main idea is to follow STEM curriculum (Gonzalez and Kuenzi, 2012; Corlu et al., 2014) which are based on real-world applications. Three applications in this field seem interesting: a cheap DAQ board, a 1/10 scale HOME I/O house model and a scale of HOME I/O garage door model.

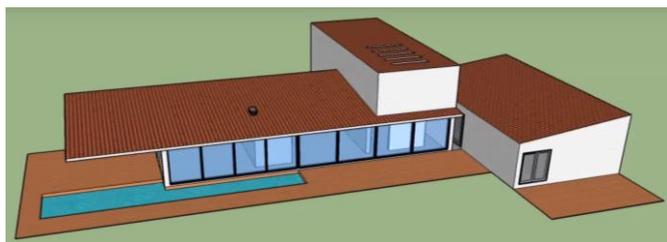


Fig. 7. HOME I/O 3D SketchUp model

In order to have HOME I/O and real world interacted together, it is necessary to use a data acquisition board. The Advantech ones with corresponding CONNECT I/O plugins initially included can be used. However the cost for the Advantech DAQ board for a French middle school is expensive. So, the idea is to use an ARDUINO Uno as a cheap digital and analog DAQ board with dedicated new plugins in CONNECT I/O (figure 8). The principle is to use a parser program in the Arduino to exchange data between the Arduino Uno and CONNECT I/O through the USB port. Thanks to these new CONNECT I/O plugins, it is therefore possible to cheaply interface HOME I/O with:

- real sensors or actuators (LEDs, buttons, switches, sensors of temperature...),
- external hardware (PLC, microcontroller...).

These plugin are really a success and are used a lot in middle schools.



Fig. 8. Plugins DAQduino

It is important to work with real systems. It is why in a middle school in Normandy, a teacher made a project with all his class to build a 1/10 scale HOME I/O house model fully instrumented with Arduino boards and Grove modules (figure 9).

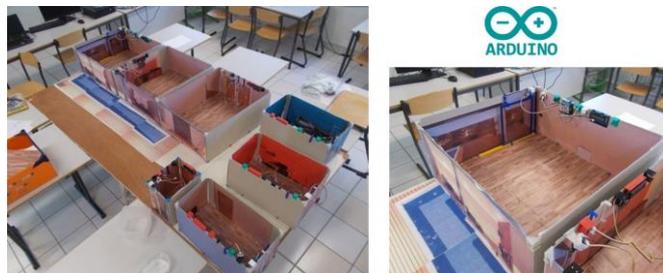


Fig. 9. 1/10 scale HOME I/O model

Grove is a modular, standardized connector prototyping system. Grove takes a building block approach to assembling electronics. Compared to the jumper or solder based system, it is easier to connect, experiment and build and simplifies the learning system, but not to the point where it becomes dumbed down. The Grove system consists of a base unit and various modules with standardized connectors. The base unit, generally a Raspberry Pi or an Arduino, allows for easy connection of any input or output from the Grove modules. And every Grove module typically addresses a single function, such as a simple button or a more complex heart rate sensor.

Based on the same idea to use real systems complementary to HOME I/O, a middle school teacher from French Center region has designed a scale HOME I/O garage door model (figure 10) made with a 3D printer. The model is controlled by an Arduino. Students use first HOME I/O, with 2 Arduino Uno boards, one as a DAQ, and the other as a controller. Like that they can test the controller, and when it works, they validate it on the “real” garage door. One can notice a “virtual commissioning” methodology, using a digital twin, like it is recommended today in the Industry 4.0 framework.



Fig. 10. Scale HOME I/O garage door model

5.2. HOME I/O at high school

In middle schools, CONNECT I/O is not really used by the students, it is just a gateway between HOME I/O and other technologies like Arduino. In high schools, CONNECT I/O can be used to initiate students to Boolean logic and controller design. Several teachers use CONNECT I/O (Modbus TCP plugins) and HOME I/O with Wireshark to initiate students about network protocol analysis.

Two other interesting pedagogical applications have been performed by a teacher from Paris in “CPGE” (classes to prepare students for the entrance examinations to the top-ranking higher education establishments). The first one uses MIT App Inventor to propose to students to develop a simple mobile application to control HOME I/O (figure 11). HTTP server, developed initially for Scratch 2.0, included now in HOME I/O is used.



Fig. 11. HOME I/O smart phone application with MIT App Inventor

MIT App Inventor is an intuitive, visual programming environment that allows everyone – even children – to build fully functional apps for smartphones and tablets. Blocks-based tool facilitates the creation of complex, high-impact apps in significantly less time than traditional programming environments. The MIT App Inventor project seeks to democratize software development by empowering all people, especially young people, to move from technology consumption to technology creation. It is a motivating way to train students about programming.

The second application deals with a practical course about Discrete Event System (DES) using MATLAB and Stateflow. A MATLAB library using HOME I/O SDK containing all the sensors and actuators of HOME I/O has been designed (figure 12). It becomes so easy to design a controller using MATLAB state machines connected to HOME I/O inputs and outputs. This practical course has got a great success.

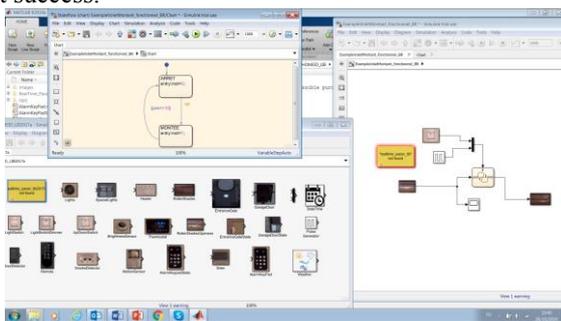


Fig. 12. HOME I/O with MATLAB Stateflow

5.3. HOME I/O at university

HOME I/O is also used in several French universities to initiate students about feed-back control (with Labview for instance) and logic control (often with CONNECT I/O). HOME I/O is used during lectures, practical courses and projects enabling new instructional strategy. For Instance at Polytech Tours, HOME I/O and CONNECT I/O are used together to train student about PLC FBD programming

language. In addition, each year a HOME I/O project is proposed to students:

- HOME I/O controlled by a Raspberry Pi with a Codesys runtime and an iPad (use of HMI Draw) as SCADA system;
- Proposal of a methodology to design a smart house and use of HOME I/O as a digital twin (Chemla et Riera, 2017);
- Supervisory control of HOME I/O using iPad, HMI Draw and Modbus TCP communication.

At UTT (Troyes Technological University), several practical courses about Boolean combinatory and sequential logic mix HOME I/O and real hardware. The goal is for instance to display the percentage of opening of a shutter on a 7-segment display type HDSP-5503 (e.g. “5” means the shutter is half open). The connection to CONNECT I/O is performed via an Advantech 4704 I/O DAQ board (figure 13). New HOME I/O licensing system enables students to prepare in good condition at home the work. At Reims Champagne-Ardenne University, HOME I/O and Scratch 2.0 have been used for a first and only course in logic control for 2nd year computer science at IUT (Riera et al., 2019). A learning from errors pedagogy strategy (Pappas, 2016; Wernecke et al., 2018) has been used to have students felt and understood the specificities of control logic, without dealing with PLC. The proposed control problems are simple, like the programming language (Scratch 2.0), but without formal specification (GRAFSET, cf. figure 14) and methods to implement, the work is not so easy at all (Pichard et al., 2018). The use of HOME I/O as a pedagogic digital twin is really adapted to a learning from errors pedagogy. This course has been a success for 2 years, students are interested and motivated as proved by questionnaires. However, teachers have to show to students that controller design based only on errors corrections is not the right way to work, at all.



Fig. 13. HOME I/O, CONNECT I/O and 7-segment display

At least, HOME I/O is more and more used for IoT (Internet of Things) teaching. The place of IoT (Internet of Things) devices is increasing in our homes. One well-known software to create links between connected devices is Node-RED, a visual tool for wiring the Internet of Things. The principle of this tool is to connect input nodes (input data) to processing nodes (to process the data) and to output nodes (to send the data). From a pedagogic point of view, Node-RED is interesting because it can combine student’s electronic systems (sensor device for example) and consumer connected devices (smart bulbs). In addition, Node-RED can be easily used with HOME I/O, using for instance the integrated web server, both for getting information from the virtual house and for activating actuators. It becomes possible to perform

original and interactive courses using for instance tools like Wooclap platform or Kahoot.

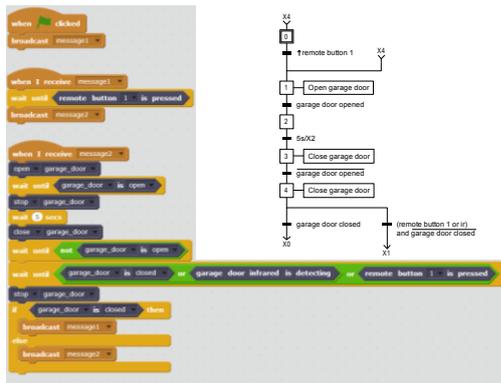


Fig. 14. Grafacet specification and Scratch 2.0 script for the garage door

This kind of courses were performed this year at Reims University and Polytech Tours where a short project (6 hours) was proposed to students after 6 hours of academic teaching. Students were free to choose the subject, and the following projects were selected:

- Close or open the rolling shutters in HOME I/O with a real connected button,
- Control the temperature of a HOME I/O room depending of a set point given by a smartphone
- Save in a database temperatures and energy consumption of HOME I/O.
- Control both a virtual light and a real connected bulb at the same time

A short evaluation has been made at the end of this session to know what the students thought about the course. For all items, evaluation was between 4.1 and 4.6 out of 5. With open questions, we noticed that they appreciated the activities, the up to date technology and some of them want to go further by themselves.

5.4. HOME I/O even at primary school!

We have noticed a use of HOME I/O in a primary school with 8 year old pupils (figure 15). In the teaching "Questioning the world », pupils have to put into practice the first notions of energy saving (lighting, heating...) and understanding and expressing themselves using mathematical, scientific and computer language. HOME I/O is used in this context as a place of discovery: heating is on but the energy consumption is null. How is-it possible? It is also a place to experiment and test hypothesis: « is it better to open the shutters during the day to consume less? ». To test their hypotheses, pupils can use the virtual tablet in the console mode to create their first computer programs. An analysis of the learning after a session showed very promising results when it comes to the three points that seem most important to primary school teacher: pupil involvement, the understanding of energy-related phenomena and of the first elements of computing.

6. CONCLUSION

After 4 years, and the updates and add-ons, HOME I/O seems an interesting simulation tool for STEM and automatic

control learners from middle school to University. This R&D project has proven that it was possible to design a pedagogical digital twin adapted to different levels of training and adapting to original pedagogical approaches like flipped classroom, pedagogic digital twin, and learning from errors, projects. The objective now is to go deeper in the analysis of experience feedback, to propose innovative pedagogical sequences to use HOME I/O.



Fig. 15. HOME I/O at primary school

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